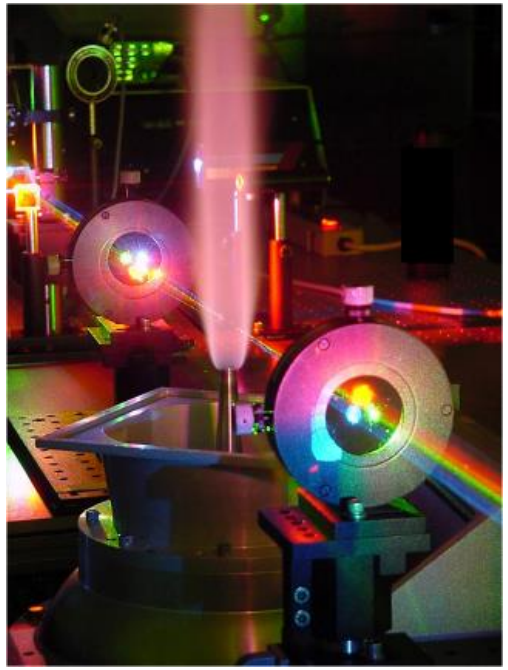
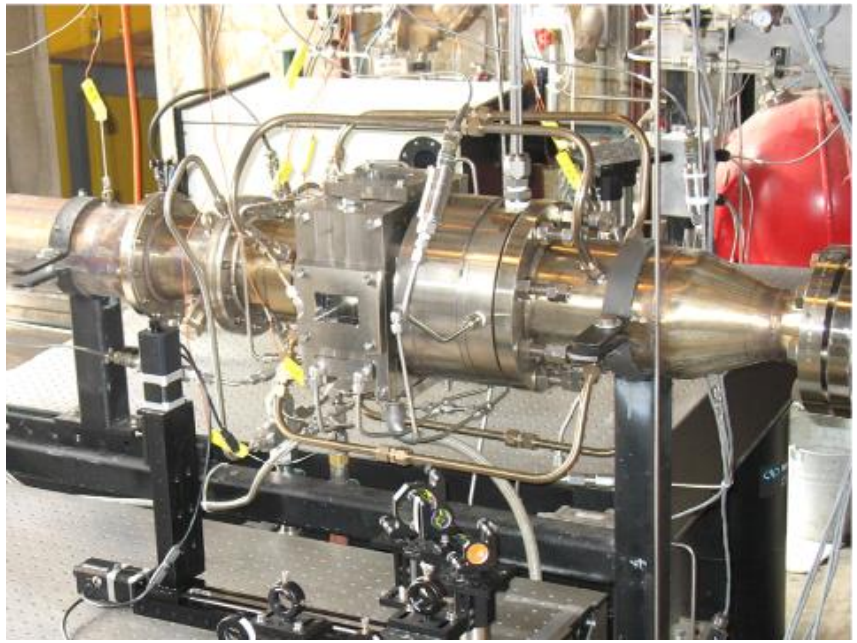
Development of Combined Dual-Pump Vibrational and Pure-Rotational Coherent anti-Stokes Raman Scattering Technique

Aman Satija and Robert P. Lucht

Motivation and Background

- **CARS in reacting flows primarily used for temperature and species concentration measurements**

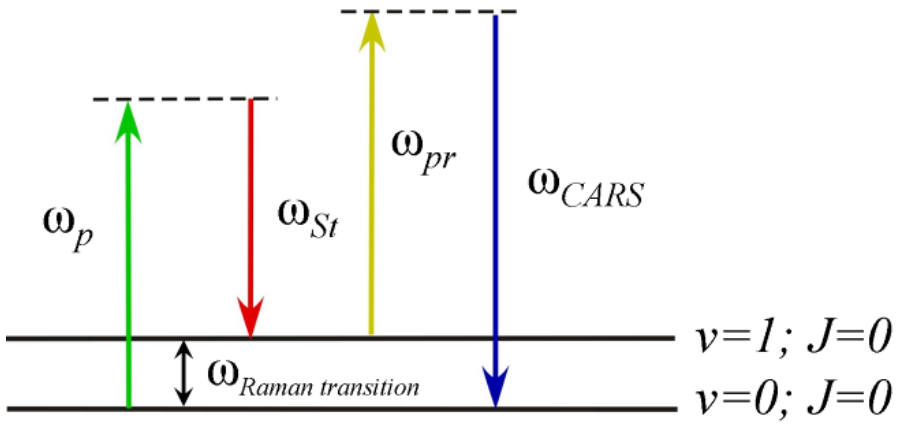




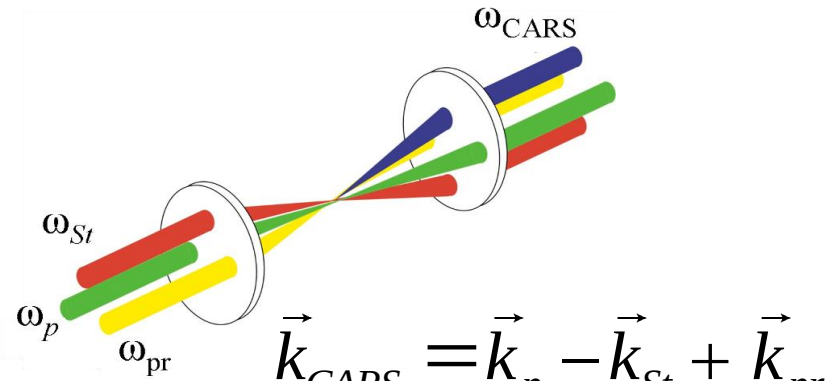
- **High Accuracy and Precision in Complex Environments**
- **Multiple Species**

Introduction to CARS

- **CARS is a third order, four-wave mixing, parametric process**



$$\omega_{CARS} = \omega_p - \omega_{St} + \omega_{pr}$$

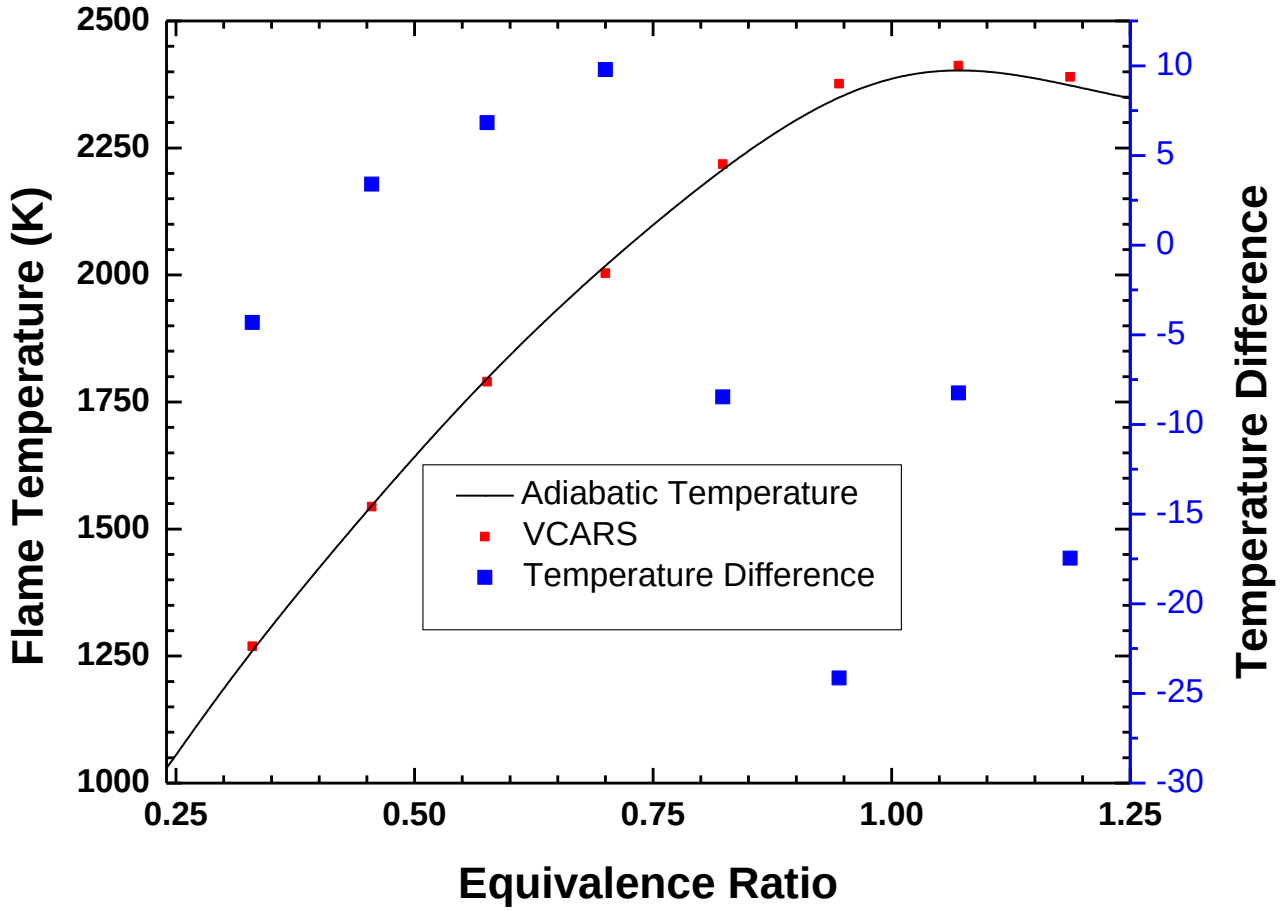


$$\vec{k}_{CARS} = \vec{k}_p - \vec{k}_{St} + \vec{k}_{pr}$$

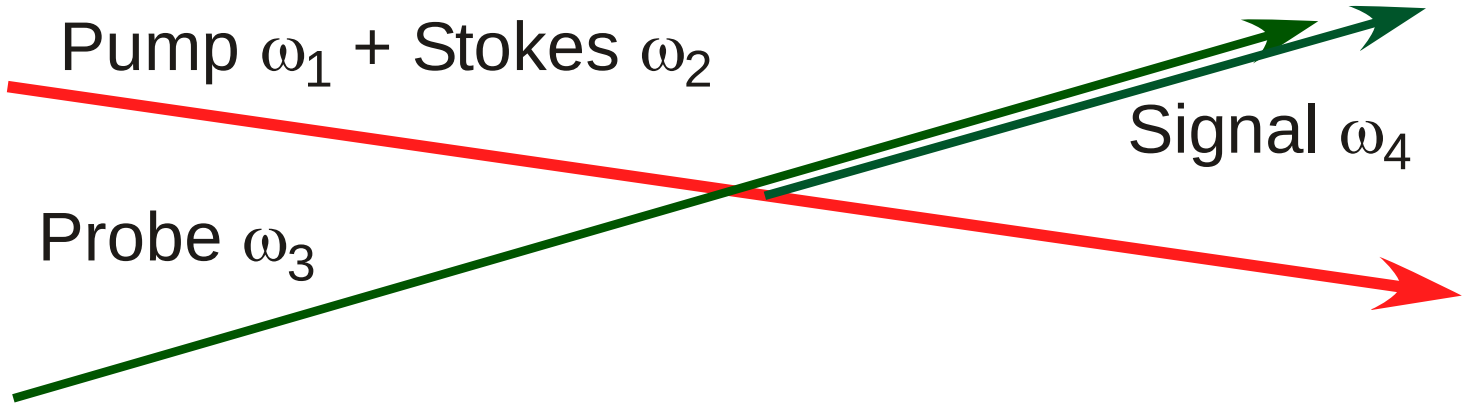
- **Time resolved and Spatially resolved**
- **Species specific and Transition specific**
- **Relatively insensitive to collisions**

Roy et al., "Recent advances in CARS spectroscopy: Fundamental developments and applications in reacting flow", *Prog. Energy and Comb. Sci.*, 2010.

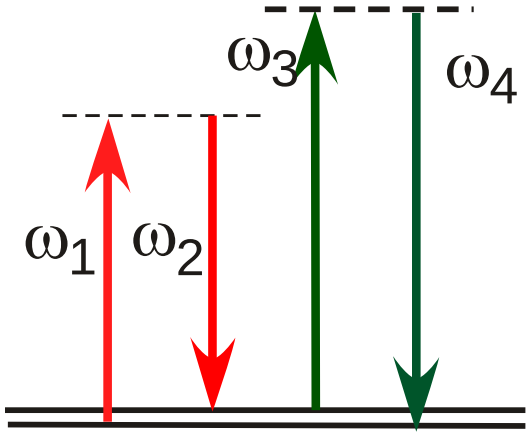
Comparison between CARS and known Temperature in a Calibration Burner

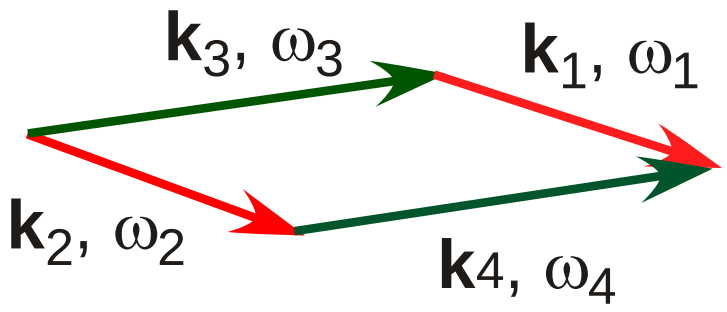


Two-beam PRCARS



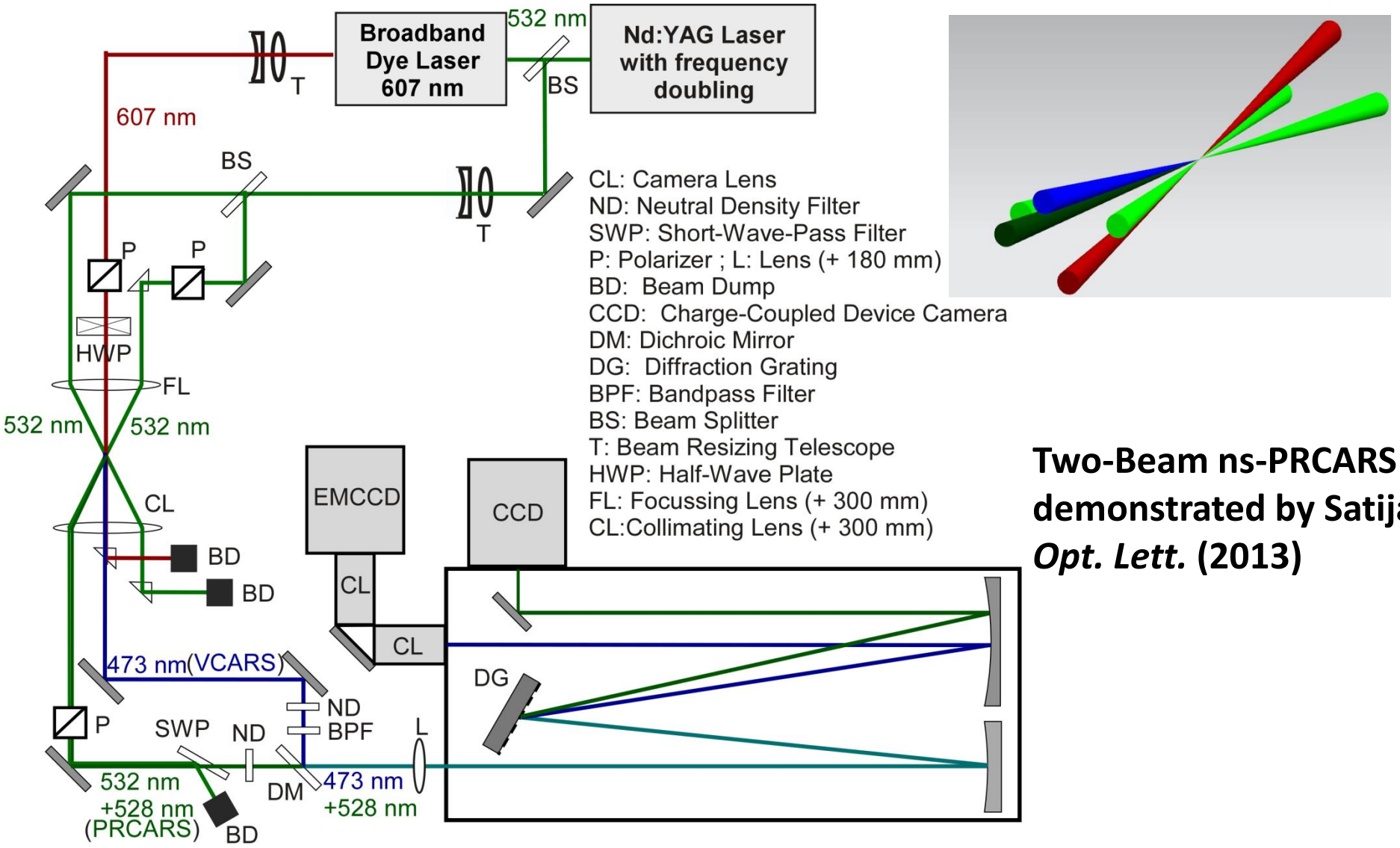
$$\omega_4 = \omega_1 - \omega_2 + \omega_3$$



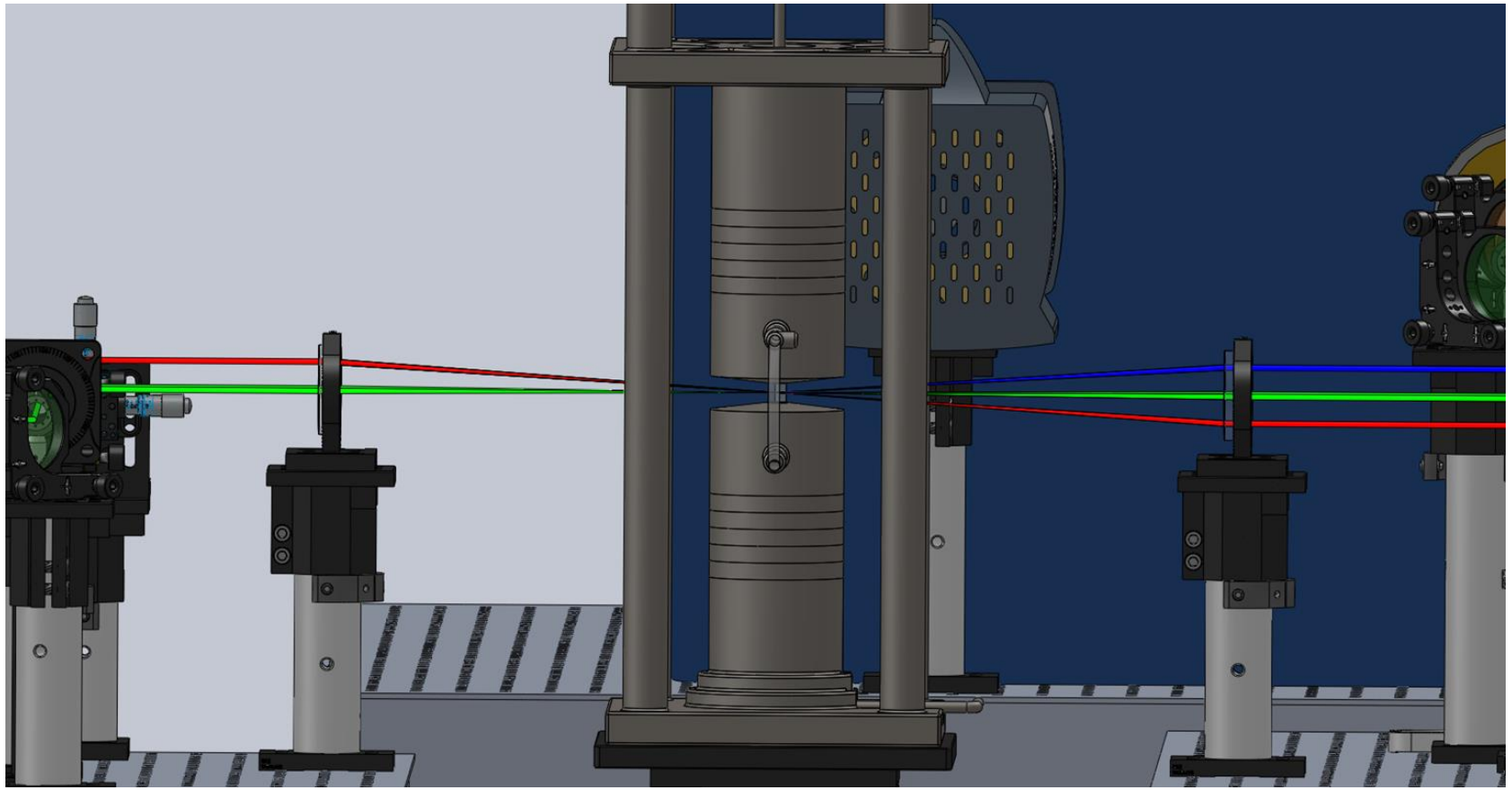


$$\mathbf{k}_1 + \mathbf{k}_3 = \mathbf{k}_2 + \mathbf{k}_4$$

Combined VCARS and PRCARS System



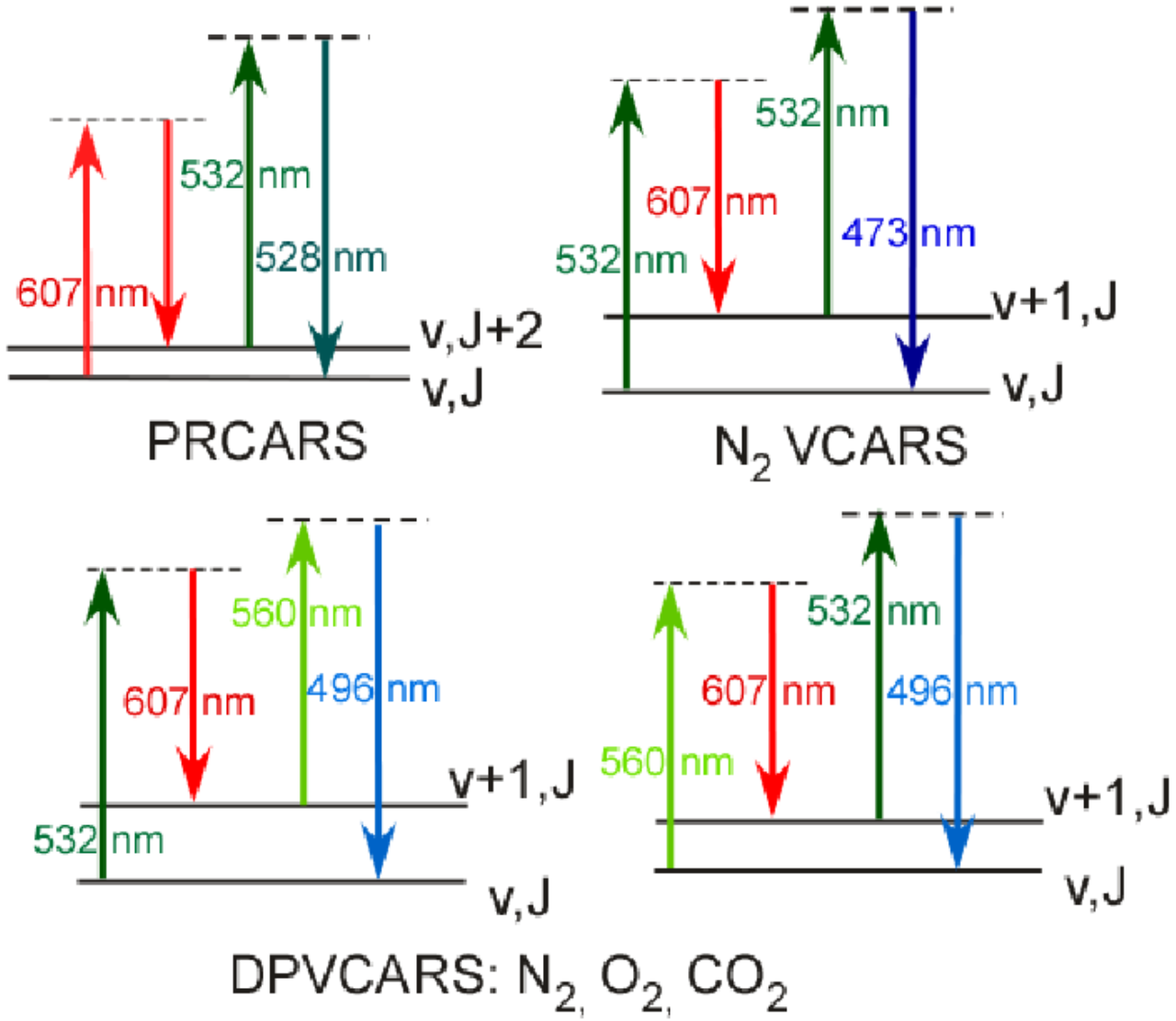
Two-Beam ns-PRCARS demonstrated by Satija and Lucht, *Opt. Lett.* (2013)



BLUE: 473 nm (N_2 VCARS SIGNAL)

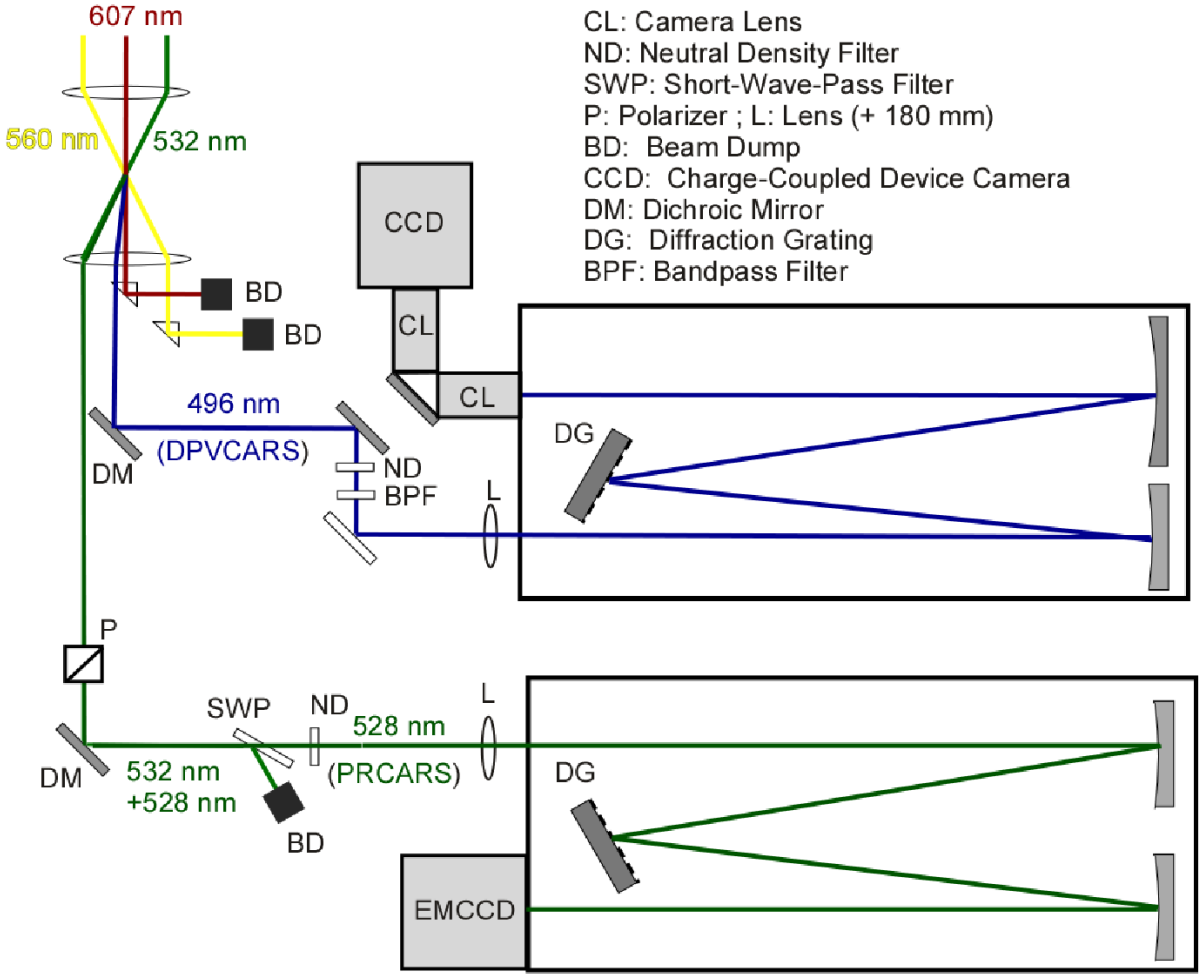
GREEN: 532.2 nm + 528 nm (PRCARS SIGNAL)

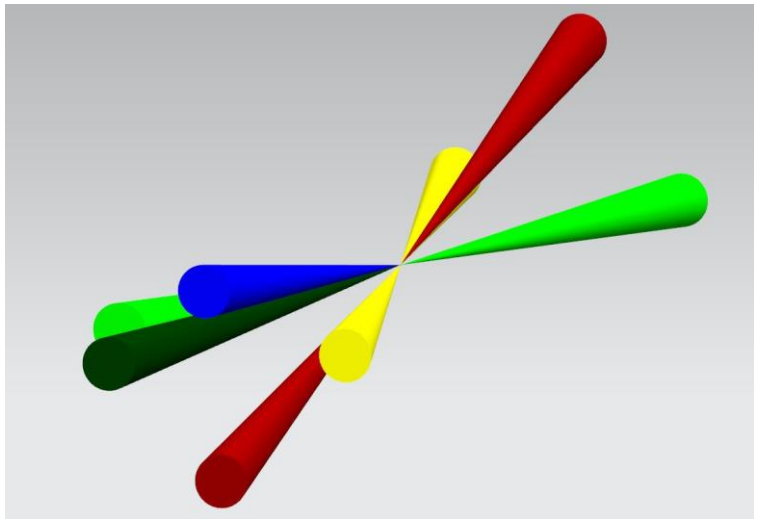
Energy Level Diagrams



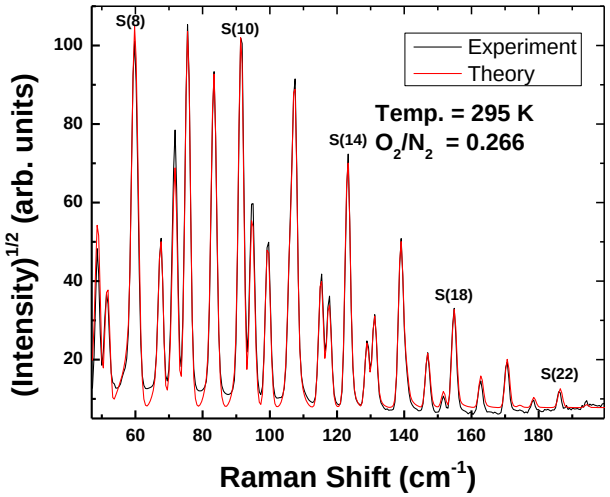
DPVCARS first demonstrated by Lucht , *Opt. Lett.* (1987)

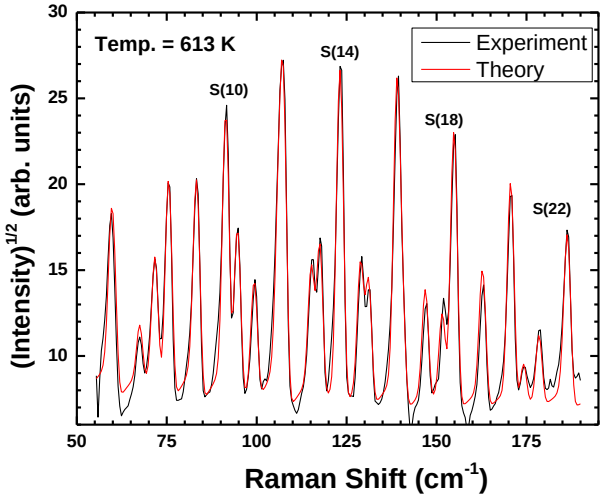
Combined DPVCARS and PRCARS System

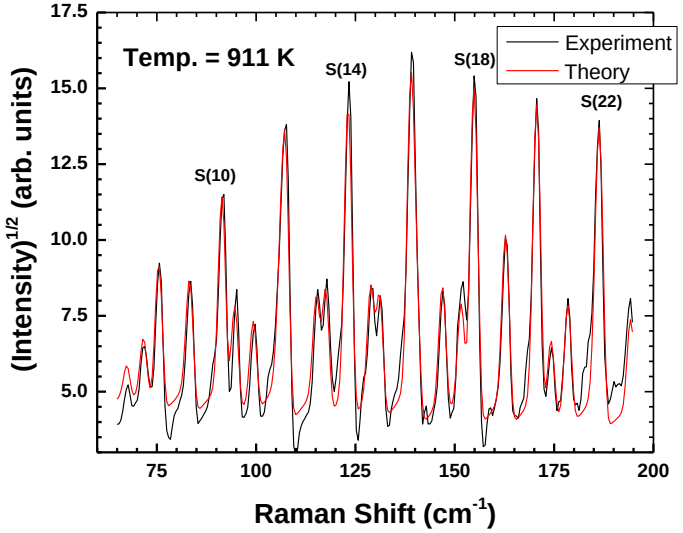


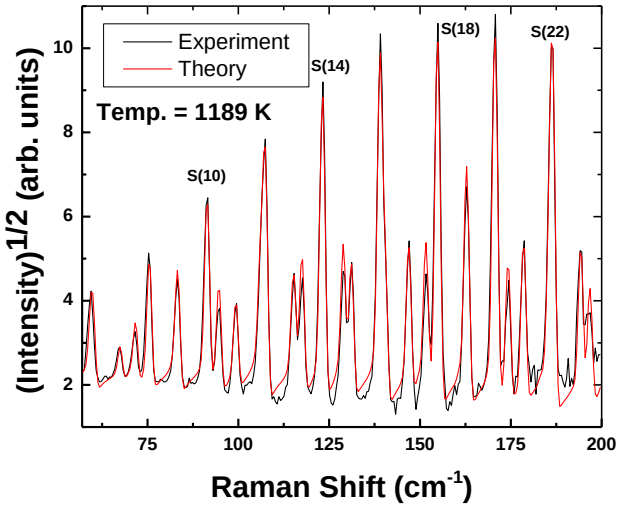


200 Shot Averaged PRCARS Spectra



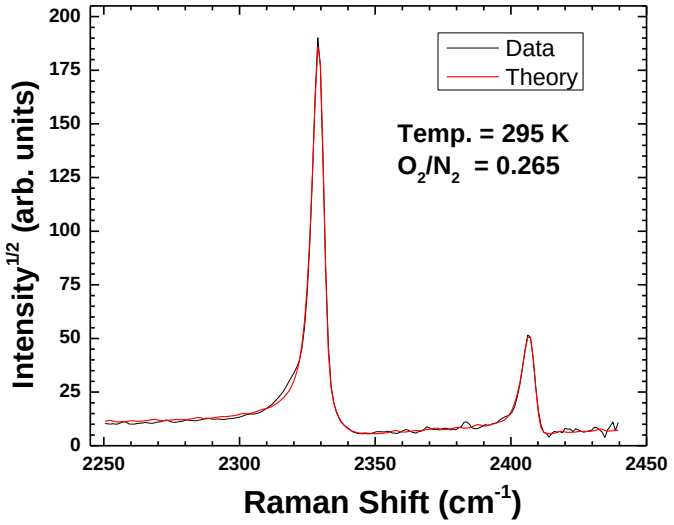


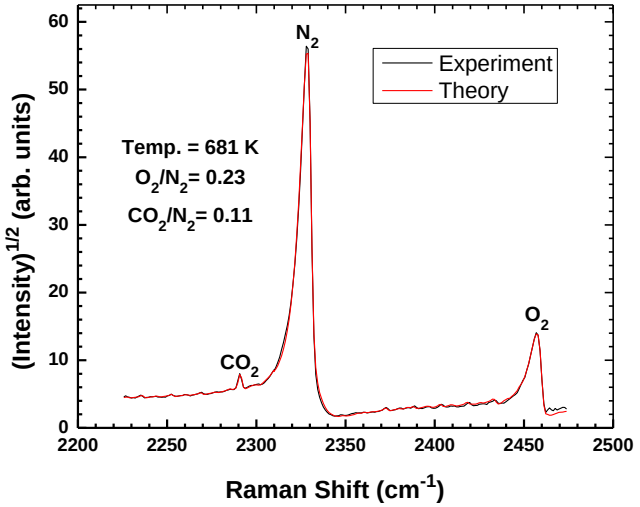


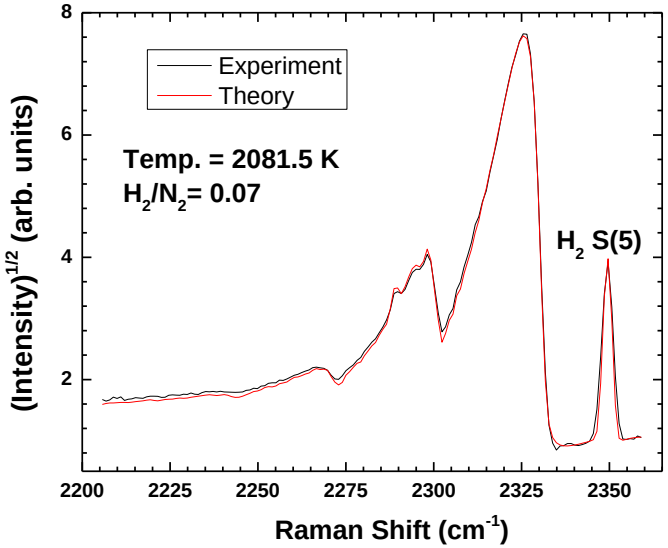


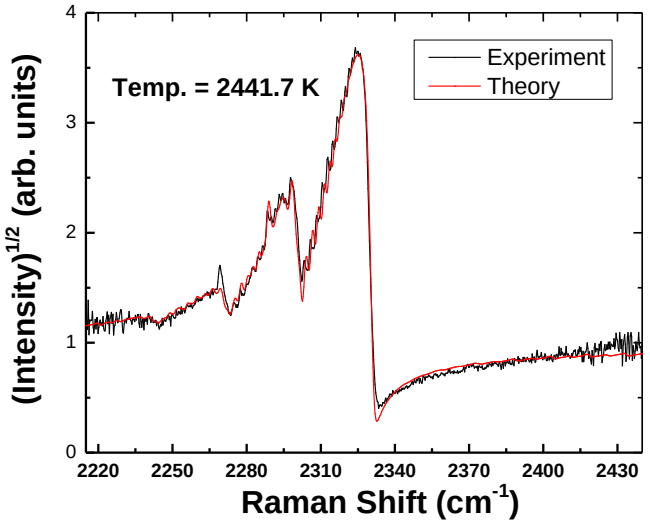
CARSFit code from Cutler and Magnotti. *J. Raman Spec.*, (2011).

200 Shot Averaged DPVCARS Spectra



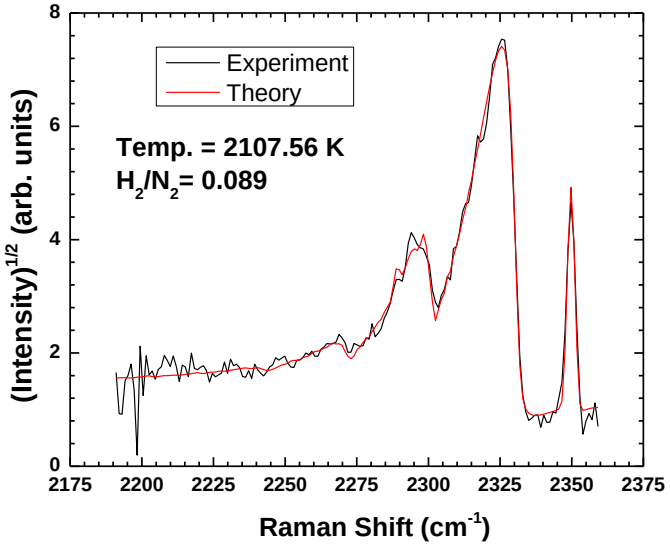


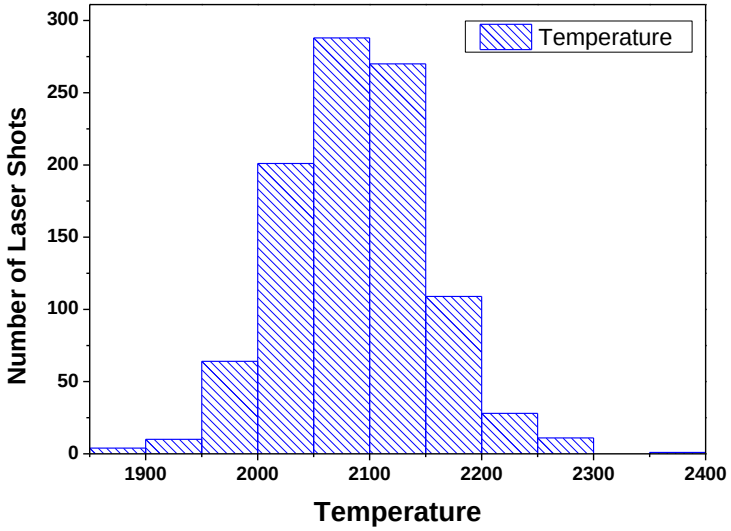


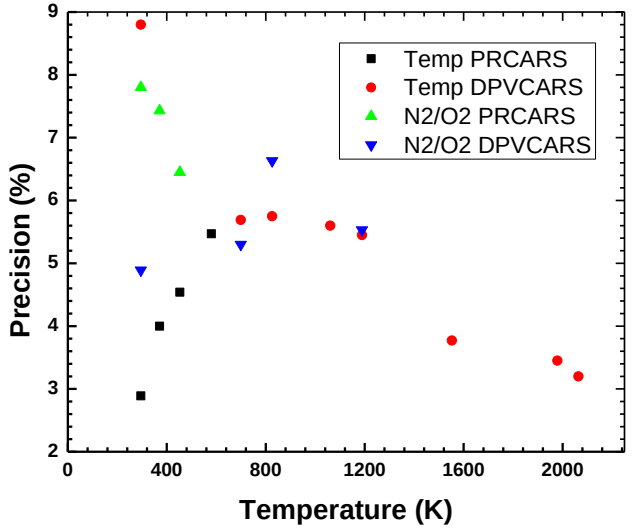


CARSFit code from Cutler and Magnotti. *J. Raman Spec.*, (2011).

Single-shot Precision of the Combined CARS System

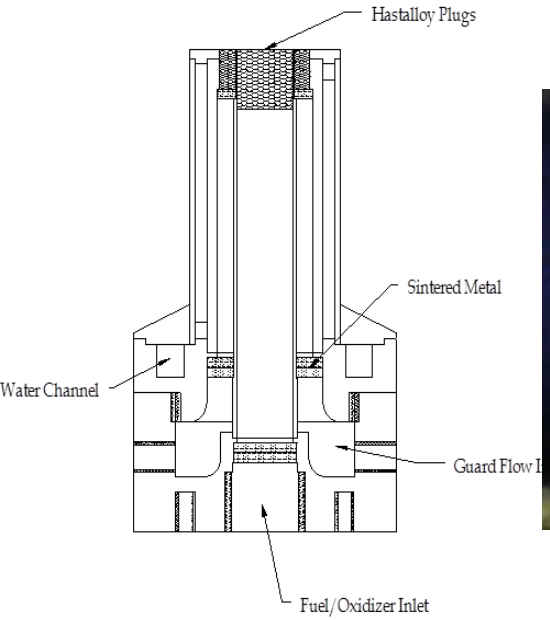






Std. Deviation of 3% . Average Temperature = 2087 K

Measurements and 1-D Simulations in Laminar Premixed Flames

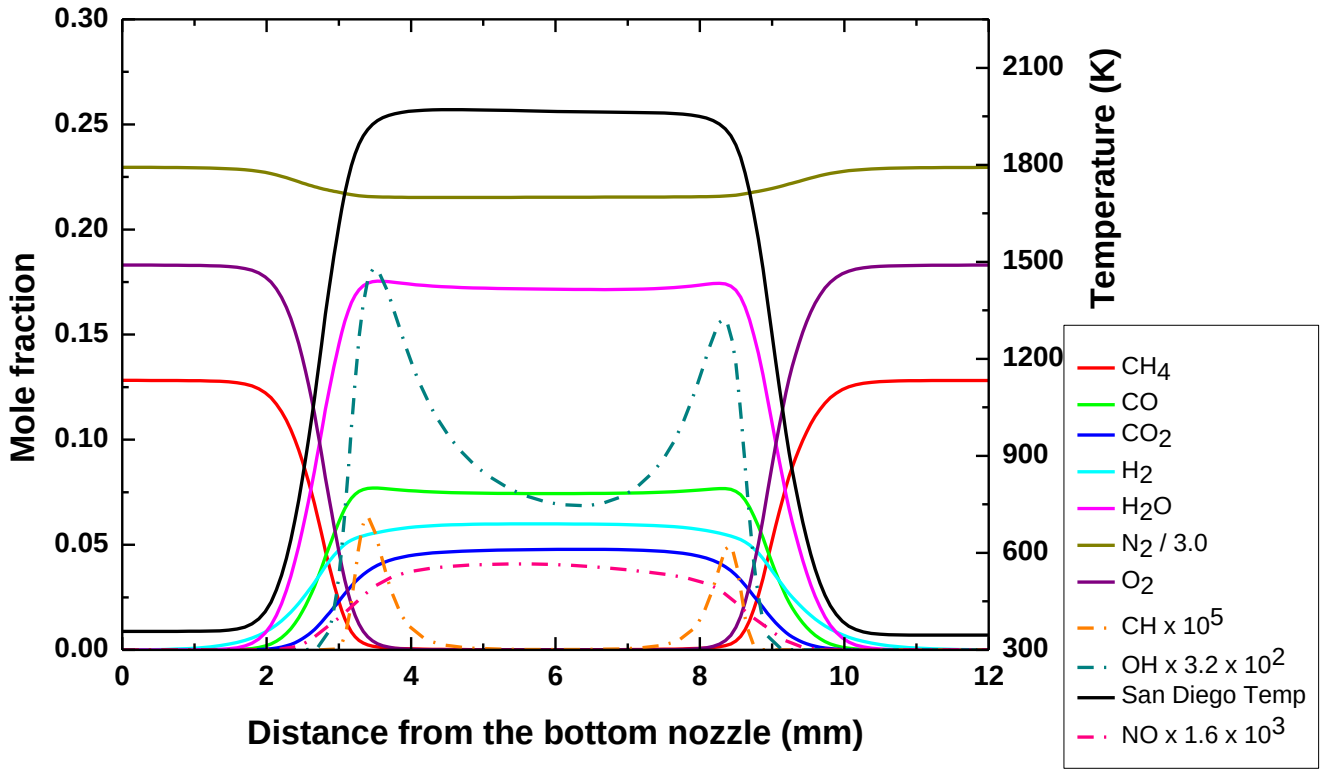


Mechanism	Giovangigli's	GRI 3.0	San Diego
Number of species	16	53	63
Number of steps	46	325	297
Typical computation time	20 minutes	3 hours	2.5 hours

- Comparison of various chemical mechanisms against CARS measurements.
- Assess influence of fuel composition and strain rate on flame structure.
- Assess Influence of transport properties such as thermal diffusion on flame structure.
- Assess Influence of radiation model on flame structure.

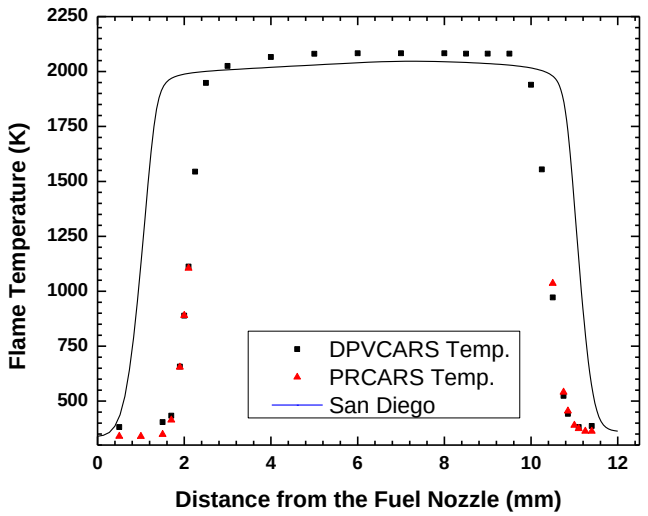
Satija et al., *Int. J. Hydrogen. Energy,* (2015)

1-D Numerical Solution of Premixed Flame Structure

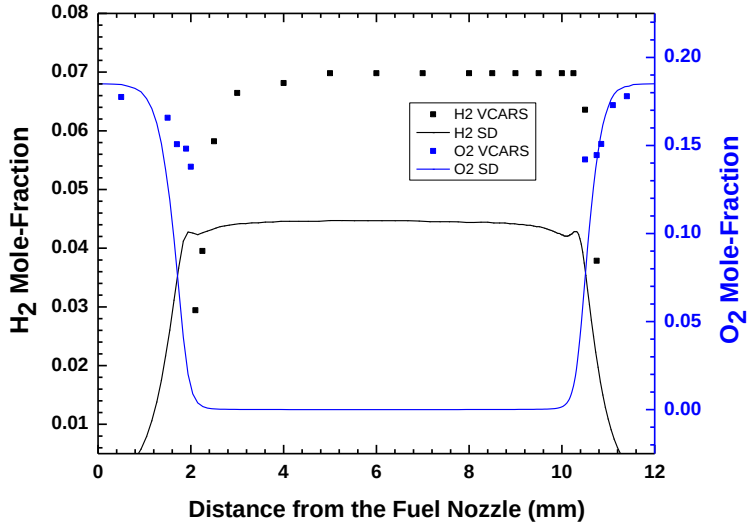


Major and important minor species at Eq. Ratio = 1.4 using San Diego chemical mechanism

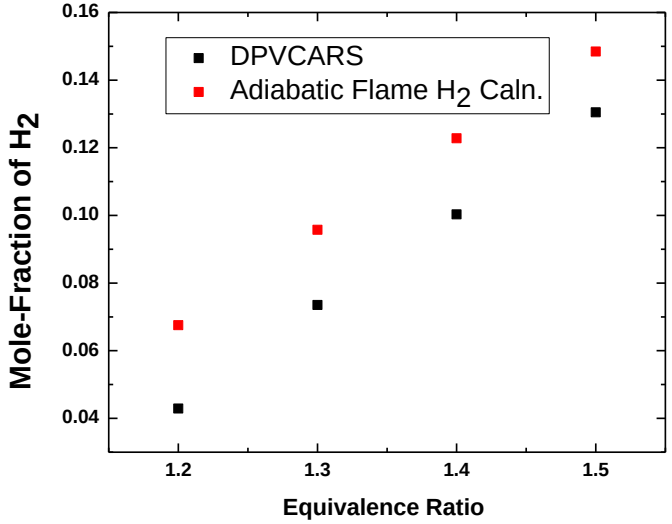
CH_4/Air Premixed Flame with varying Equivalence Ratios



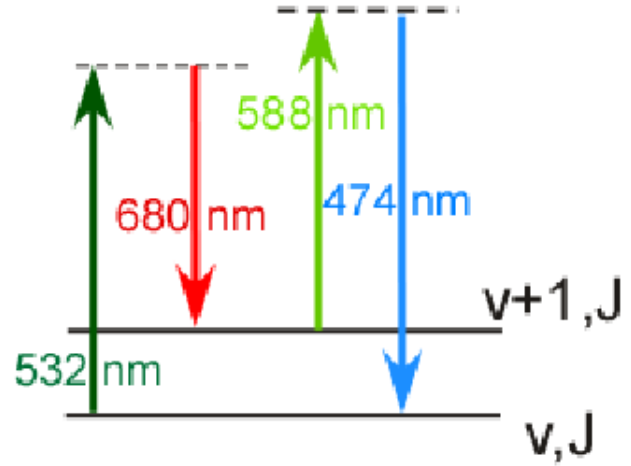
Comparison of Flame temperature for Eq. ratio = 1.31

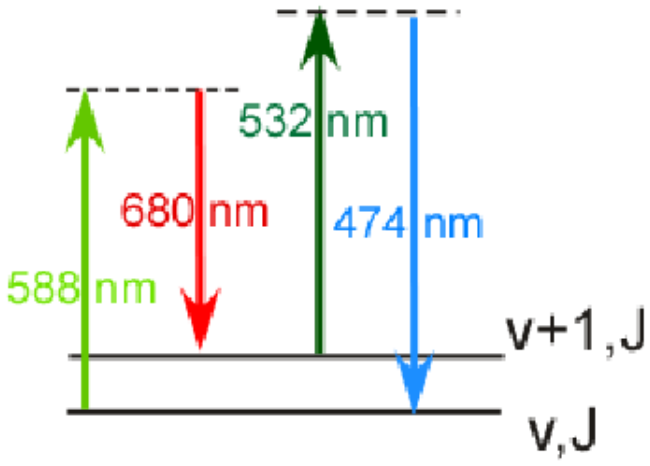


Comparison of H_2 and O_2 mole-fraction for Eq. ratio = 1.31

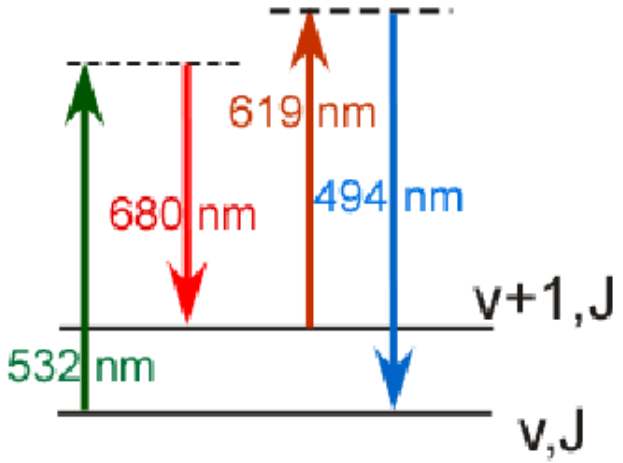


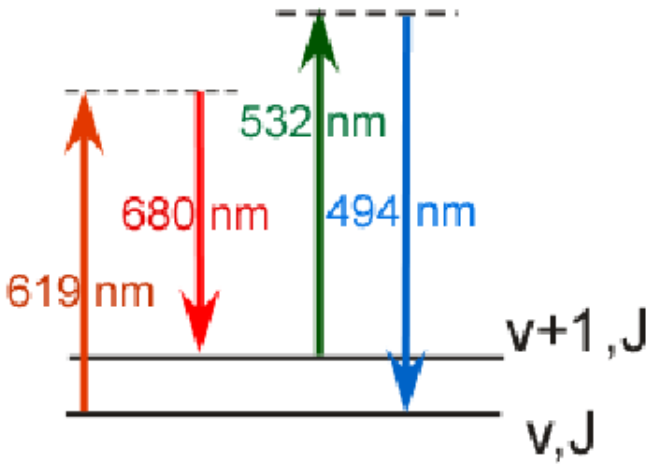
Other DPVCARS Possibilities





DPVCARS: N_2, H_2,





DPVCARS: H_2, O_2, CO_2

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